

Reply to the comment of Chudnowski and Garanin on Phonon Assited Tunneling in Mn_{12} (PRL 83, 416 (1999))

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Chudnovsky and Garanin have attacked harshly our paper [1] in a comment in arXiv:cond-mat [2]. They write in their comment that “all formulas of Ref. [1] are incorrect”. They question “how can Δ be the magnetic dipole matrix element and the tunneling splitting at the same time?”. These two Δ are obviously different and we write it explicitly in the text:

- The first Δ appears in the expression of the fundamental doublet:

$$\sqrt{\Delta^2 + \epsilon^2} \quad (1)$$

Δ is called the tunneling rate and ϵ is a Zeeman term. We seize the opportunity of restablishing the historical truth of Eq. 1. It is Korenblit and Shender who the first have pointed out that high spins with large anisotropy give tunneling states, have resolved analytically the Hamiltonian in the high-spin approximation and have given the explicite form of Δ in Eq. 1 [3]. This is often ignored by the MQT community.

- In our paper there is a second Δ which is obviously different from the first one. We write (Eq. 3 of our paper):

$$\chi'' = CN\Delta^2 T_2 \tanh\left(\frac{\hbar\omega}{2k_B T}\right) \quad (2)$$

and then we write: “where Δ is the magnetic dipole matrix element between the two states of the fundamental doublet”. We take the same definition as Abragam and Bleaney in their formula that has been called “trivial” by Chudnowsky and Garanin [4]. Hence, this Δ is explicitly different from the first one which is the splitting (equal to $\hbar\omega_0$, where ω_0 is the resonance frequency and depends on the applied magnetic field).

Another way to show that the two Δ are different is to treat the fundamental doublet as an effective spin $S = 1/2$ and to write the Hamiltonian:

$$\mathcal{H} = \mathcal{H}_0 + \mathcal{H}' \quad (3)$$

where \mathcal{H}_0 is the unperturbed hamiltonian in the representation of the unperturbed eigenstates $|1\rangle$ and $|2\rangle$. The eigenstates are coupled to the electromagnetic field, which gives \mathcal{H}' . In our case the magnetic field is perpendicular to anisotropy axis. So, the Zeeman term is zero and the splitting $E = \sqrt{\Delta^2 + \epsilon^2}$ is Δ . Then the Hamiltonian is:

$$\mathcal{H} = 1/2 \begin{pmatrix} \Delta & 0 \\ 0 & -\Delta \end{pmatrix} + 1/2 \begin{pmatrix} \delta & M \\ M & -\delta \end{pmatrix} \quad (4)$$

where M is the matrix element $\langle -|\mathcal{H}'|+ \rangle$ and δ is negligible as compared with Δ . The second Δ in our paper is now M . It is this matrix element which induces absorption (and/or emission) of electromagnetic quanta and transitions within the fundamental doublet, these transitions being obviously tunneling transitions.

Eq. 2 gives a susceptibility χ'' constant at low temperature ($\hbar\omega < k_B T$). However, we observe a strong increase of χ'' with increasing temperature. The only parameter in Eq. 2 is Δ (the second one of our paper or M now), which means that this one increases with temperature, i.e. when phonons are added. This is an experimental fact.

To conclude, the attack of Chudnovski and Garanin upon the tunneling rate in Mn_{12} is absolutely irrelevant.

References

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- [3] I. Ya. Korenblit and E. F. Shender, Sov. Phys. JETP **48**, 937 (1978).
- [4] A. Abragam and Bleaney, "Electron Paramagnetic Resonance of Transitions Ions", Dover Publications, New York (1986).